High-Resolution Measurement of Sediment Concentration in Convectively Unstable Sediment Clouds

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LONG-TERM GOALS

To understand the mechanics of small-scale sediment-fluid interactions and develop state-of-the-art technology to observe these processes in the field. Convective sedimentation (CS) and preferential concentration (PC) represent two newly formulated processes that have the potential to change the way the way we think about delivery of riverine material to the continental shelf and beyond. Despite substantial indirect evidence, neither CS nor PC has not been observed directly in the field; most likely a result of existing instrument limitations.

OBJECTIVES

- To measure the constituents (sediment concentration and salinity) in a turbulent water column of settling fine sediment.
- To examine the effects that natural fine sediment (as opposed to manufactured materials) play on the dynamics of particle-fluid and particle-particle interactions.
- To utilize new tools for the measurement and identification of water-column variability. These instruments will be tested and calibrated such that they will ultimately be used for field measurement.

APPROACH

We have modified an existing laboratory flume, which produces a steady flow of fresh, sediment-laden fluid above a clear brine, to perform our experiments. The facility complements existing tank experiments that examined convective processes in the absence of turbulence (Parsons et al., 2001). Using a variety of instrumentation, we have identified the environmental variables regulating removal of sediment from the water column by convective means. Dimensional analysis allows us to formulate dimensionless variables that can reliably predict vertical sediment fluxes in unconstrained environments. Examination of the deposits in the saline basin (Figure 1a) can identify the sorting mechanisms within the convective plumes.

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WORK COMPLETED

- Established the inability of existing optical tools (FOBS-7) to identify and characterize sediment-concentration variability in natural water columns.
- Identified the lower limit on the ability of a stably stratified plume to initiate mixing-induced convective sedimentation (~300 mg/l; Figure 1).
- Identified the dimensionless variable responsible for regulating mixing-induced convective sedimentation (Figure 2a) and related it to the initial volumetric concentration (the lone independent variable of interest).
- Discovered the presence of preferential concentration in both experiments of environmental suspensions and in natural flows (Figure 2b).

RESULTS

We have established that suspensions can organize themselves to rapidly deposit material at riverine sediment concentrations commonly measured on fluid-mud-producing margins (300-1000 mg/l). The result of these processes on the remaining sediment in the water column appear qualitatively similar to some unpublished data of steep margins (e.g., the Sepik River, Papua New Guinea; Kineke et al., 2000). These concentrations are also substantially less than what has been discussed previously in the literature to produce convective motions (10 g/l, Maxworthy, 1999; 1 g/l, Parsons et al., 2001). We were able to perform experiments that identified the relationship between the dimensionless vertical flux of sediment and the volumetric concentration of sediment initially in the water column (Figure 2a). These results will be summarized in Wayne McCool's MS thesis, which will be submitted for publication at *Continental Shelf Research* in the coming weeks.

Our tests of the FOBS-7 sediment concentration probe failed to demonstrate the FOBS-7's ability to accurately measure sediment-concentration variability. Older, well-established equipment (OBS-1) designed to estimate the average concentration in a relatively large volume was equally effective at measuring general (qualitative) variability in the sediment concentration associated with turbulent motions. However, neither device was capable at quantitatively describing sediment-concentration variability at the length-scales relevant for CS, PC and remote-sensing data. Future instrument development to counteract these problems is underway as part of an affiliated NSF Major Research Instrumentation initiative.

Preliminary evidence of PC, the ability of a turbulent suspension to produce areas of high and low concentration, emerged from analysis of sediment deposited in the saline basin (Figure 1a). In the experiments, fine material (<10 mm) was preferentially removed the water column in the basin section. Using a simple analysis and relationships proposed by other workers (Maxey, 1987; Hogan and Cuzzi, 2001), we were able to link this observation with the presence of PC in our experiments.

IMPACT/APPLICATIONS

The discovery of convective transport processes in turbulent fluids at concentrations less 1 g/L represents a significant scientific finding. Most rivers (even benign, passive-margin rivers) produce

these concentrations during floods. Though mouth geometry, tidal characteristics and estuarine mixing processes will most likely downplay the prevalence of CS in low-energy rivers, there are certainly numerous situations where conditions will be favorable for this transport mode. For instance, low-latitude rivers produce these concentrations consistently and for long durations. In these systems, distribution of material is likely affected by CS.

Our experiments have now given numerical modelers the first step into integrating this process into their models. Ongoing collaboration with Jasim Imran (University of South Carolina) will integrate our simple relations into his large-scale models of river plume dynamics.

TRANSITIONS

We hope that the simple CS models we are developing will be used in conjunction with the margin models being developed to predict margin morphology and stratigraphy (e.g., Syvitski and Hutton, 2001; Kassem and Imran, 2001).

Our results should help guide observations made by field workers and help them develop strategies for observation of sediment-concentration variability and convective transport in natural systems.

RELATED PROJECTS

This project is closely related to fluid-mud experiments investigating the interactions of surface gravity waves and turbid bottom boundary layers. Details about the fluid-mud experiments can be found at: http://www.ocean.washington.edu/people/faculty/parsons/research.

Model results will be compared to field data acquired by Andrea Ogston as a part of the EuroSTRATAFORM program. Her study involves the seasonal delivery of sediment to the water column in the proximity of the Po and Apennine river systems. There is significant potential for the use of the FOBS-7 on future cruises. In addition, our findings are complementary to the examination of the 2000 Po flood deposit being performed by Chuck Nittrouer; again, in conjunction with the EuroSTRATAFORM program.

The simplified models produced from our results will be used in conjunction with numerical models produced by Jasim Imran and James Syvitski, for ultimate use in ***Sedflux***.

A recently funded NSF Major Research Instrumentation project (with Andrea Ogston) specifically addresses the needs of field instrumentation. The project intends produce a probe that can measure in small sampling volumes (like the FOBS-7), but will also measure multiple adjacent points and in high fine-sediment-concentrations (i.e., > 1g/l).

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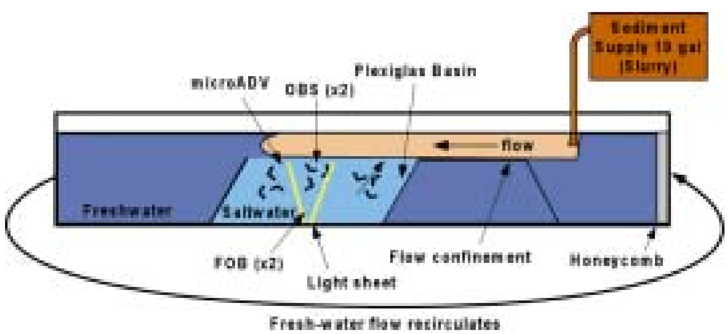

Figure 1a) Left: Schematic description of modified experimental facility. The material used in the experiments was obtained from STRATAFORM cores of the upper Eel Canyon. b) Right: Low-concentration experiment

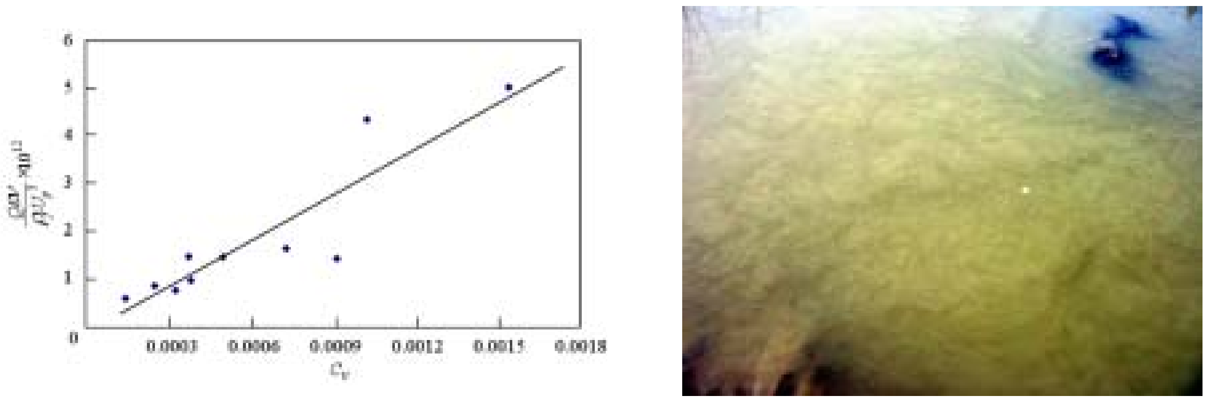

Figure 2a) Left: Dimensionless collapse of experimental data. The two parameters plotted are the dimensionless vertical flux and volumetric sediment concentration Cv. The vertical sediment flux Q is made dimensionless by the plume velocity, Up, the viscous dissipation rate, e, the kinematic viscosity, n, and the density of interstitial fluid, rf. b) Right: Photograph of the Toutle River in the spring of 2001. The variability of lighting in the stream is associated with increased backscattered light in areas of higher sediment concentration.